Adaptive control of safety margins in driving

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Summary

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Introduction

In the past decades, traffic density has increased considerably. As traffic density increases, distances between cars decrease and drivers have to deal with cars driving in front of them a larger proportion of time. Thus, distance keeping and adequate reactions to decelerations of cars driving ahead become increasingly important in high traffic density. However, despite the increase in the number of cars on the roads, the number of serious accidents has decreased. This illustrates the fact the drivers are able to adapt their behaviour to changing circumstances. Therefore, traffic safety research should focus not only on the study of drivers' skills, but above all on the adaptation of driving behaviour to traffic circumstances. This thesis concerns the adaptation of driving behaviour in distance keeping and the avoidance of rear-end collisions.

Driving is a complex, dynamic task. Successful performance in driving can be defined as the adaptation of behaviour to performance constraints in order to reach the destination without accidents. The execution of the driving task depends on the driver's skill level, but also on motives and expectations. The expectations of the driver and the predictability of the situation determine both tactical decisions such as choice of speed and headway and reactions to discrete events. In order to be able to specify hypotheses about the adaptation of driver behaviour in ever-changing circumstances, it is necessary to make assumptions about the intentions of the driver. There has been considerable discussion in traffic safety research about the intentions of drivers. The main topic in this discussion is the role of risk in the control of driver behaviour. Some models of driver behaviour assume that speed choice is determined by rational estimations of accident risk. It can be assumed that risk certainly plays a role in the control of driving behaviour, but it seems more realistic to define perceived risk as a feeling of fear or uncertainty rather than an estimation of accident probability. Uncertainty depends on the predictability of the traffic situation and on the time available to react to potential hazards. It can be assumed that drivers choose their speed in such a way that the time available to react to hazards is perceived to be sufficient.

A very useful idea is that risk control during driving is based on maintaining safety margins. Thus, drivers do not consciously estimate and control risk during driving, they simply adjust and maintain safety margins, which can be done by applying routine situation-specific decision rules. Safety margins are usually described in terms of time rather than distance. There are two time-based safety margins that are used in the study of distance-keeping behaviour: *time headway* and *time to collision*. Time headway is defined as the distance between two cars divided by the speed of the following car. This is comparable with the amount of time between the moment a car passes a certain point on the road and the moment the next car passes the same point. Time to collision is defined as the distance between two cars divided by the speed difference between these cars. Thus, time to collision reflects the time it would take before a collision would occur if the relative velocities of the two vehicles remain unchanged. It is possible to calculate time to collision for any situation in which the speed of the lead car is lower than the speed of the following car. Minimum time headway and minimum time to collision can be used as indicators of criticality in conflict situations. This thesis focuses on the control of time-related safety margins in changing circumstances.

Driving involves the continuous updating of knowledge about the position and behaviour of other road users. Drivers need to have an adequate representation of the traffic situation at any moment, in order to avoid collisions and to judge whether it is possible to carry out a certain manoeuvre. Driving involves the ability to select relevant information and to ignore irrelevant information. Expectations guide the perception of relevant information. The other way around, perception guides expectations. Thus, drivers have expectations about what is likely to happen in a particular situation, which creates the possibility to anticipate future traffic circumstances. Anticipation is more than merely expectation or mental preparation. It includes actions based on expectations, in the form of anticipatory responses that are carried out before the actual hazard is present.

Complex task performance involves not only the planning of actions, but also feedback processes in order to check whether action steps have produced the desired results. It can be assumed that drivers monitor the efficiency of their performance. That is, they evaluate the quality or effectiveness of their performance in relation to the task goals and the effort costs associated with this performance level. In the course of prolonged driving, the motivation to invest effort in a task decreases and it becomes increasingly difficult to focus attention. If the effort costs increase or if the motivation to invest effort in the task decreases, drivers can decide to carry out the task in a different way. In particular, drivers can drop low-priority task goals in order to maintain adequate performance at acceptable effort costs.

It can be concluded that there are two reasons why human operators are able to carry out complex tasks rather efficiently. Firstly, skilled operators have a mental model about the task, which allows them to select the relevant information. Secondly, operators can monitor the efficiency of performance and adapt their performance strategy to changing circumstances. The experiments described in this thesis concerned the role of anticipation and behaviour adaptation in driving. In particular, the studies focused on the choice and control of time headway in dynamic distance-keeping situations that involved speed differences with respect to the lead car.

The driving simulator

All experiments described in this thesis were carried out in a driving simulator. Simulator research allows the systematic manipulation of the traffic situation and the expectancies that guide driving behaviour. All participants can be confronted with the same traffic situation and the situation can be repeated with small variations. Clearly, the experiments that were described in this thesis could not have been performed on the road. Obviously, it is very important to know whether driving simulators are valid research tools. There are some indications that individual differences in driving behaviour are reflected in driving behaviour in the simulator. Even if the exact speed and headway chosen in the simulator do no correspond with the tactical choices in reality, it can be assumed that the factors that affected the control of speed and headway in the simulator will also affect driving behaviour in reality.

The experiments

The study that is discussed in chapter four focused on avoidance responses to decelerations of the lead car. In particular, this experiment addressed the question how drivers adjust their reactions to the deceleration level of the lead car and how expectations affect these reactions. It was assumed that abrupt decelerations of the lead car are easier to perceive than gradual decelerations. Moreover, it was hypothesised that predictable decelerations would be perceived earlier than unpredictable decelerations. The driver's expectations were manipulated by means of situational traffic cues. In predictable deceleration scenarios, the lead car had to give way to a vehicle that was coming from the right. In unpredictable deceleration scenarios, there were no indications that the lead car was going to decelerate. The results show that the response times and deceleration levels were very well adjusted to the development of criticality in deceleration scenarios. Drivers adjusted the timing and accuracy of their reactions according to a strategy that resulted in equal minimum time headways for abrupt and gradual decelerations. Furthermore, reactions to predictable decelerations were faster than reactions to unpredictable decelerations. Drivers increased their headway if they expected a deceleration of the lead car. The anticipatory increase of headway and the faster reactions to predictable decelerations resulted in larger minimum time headways. Thus, anticipation based on contextual cues allows drivers to maintain the preferred safety margins. This study has shown that preview is essential in the control of safety margins, because it allows drivers to build expectations about possible future threats.

Chapter five describes two experiments on the effects of fog on the control of safety margins. In fog, uncertainty about the presence and behaviour of other vehicles is increased. The first experiment was conducted in order to answer the question whether the choice of headway and reactions to decelerations are affected by reduction of preview and whether changes in distance-keeping behaviour are related to perceptual difficulties or to reduced possibilities for anticipation. This study showed that drivers increased their headway in reduced visibility conditions. Stimulus degradation due to reduced visibility did not affect the accuracy of reactions to decelerations, and it was concluded that the adaptation of headway was related to uncertainty about the presence and behaviour of other vehicles. If drivers maintain a longer time headway, the time available to react to decelerations of the lead car increases. The second experiment was carried out in order to study the effects of time pressure on the adaptation of headway to visibility conditions. One group of participants was instructed to drive on a tight time schedule. It was possible to arrive at the destination in time without violating the speed limit. The other group of participants received no specific time-schedule instructions. The results showed that drivers did not increase their headway in reduced-visibility conditions if they had to drive in time-schedule conditions. However, drivers in the time-schedule condition were able to react very accurately in response to decelerations of the lead car. As a result, the minimum time headway was not shorter for the time-schedule group than for the control group. Furthermore, even though the time-schedule group drove at a higher speed, criticality in the approach of a slow car was not increased for this group. It can be concluded that drivers adjusted their reactions according to a strategy that resulted in equal criticality for the time-schedule group and the control group. The strategy chosen by the time-schedule group is presumably very demanding because it requires continuous alertness of the driver in order to react adequately.

Chapter six describes an experiment on the effects of fatigue due to prolonged driving on distance-keeping behaviour. The research questions were whether distance-keeping behaviour changes in the course of prolonged driving and whether this interacts with time-schedule instructions. The motivation to invest effort in a task often decreases in the course of prolonged performance. It was assumed that drivers would increase their headway in order to restrict the effort costs of driving. The results showed that there was indeed a tendency to maintain longer headways, but the accuracy of reactions to decelerations of the lead car and slow cars driving ahead was not affected in the course of prolonged driving. In general, performance on subtasks with a relatively low priority, such as steering, deteriorated whereas performance on high-priority tasks, such as collision avoidance, remained intact. The results indicate that fatigued drivers try to restrict the effort costs of prolonged driving while protecting primary performance goals. Time schedule instructions resulted in a lack of adaptation of the performance strategy in reduced visibility conditions. As a result, criticality was increased for the time-schedule group, in particular after prolonged performance. Thus, the lack of adaptation of speed and headway was not fully compensated by an increased accuracy of reactions. It was concluded that the combination of fatigue and time pressure is potentially dangerous because the adaptation of driver behaviour to changes in traffic circumstances is insufficient and safety margins are relatively short.

Conclusions

The experiments described in this thesis show that there are three types of adaptation that allow drivers to cope with task demands and maintain safety margins. *Operational adaptations* are changes in the timing and the accuracy of avoidance responses. Drivers adapt their reactions to the urgency of the situation in a manner that allows them to maintain constant safety margins. *Tactical adaptations* are adjustments of speed and time headway. If drivers maintain a lower speed or a longer headway, they can reach the same criticality with less accurate reactions. It can be concluded that tactical choices in driving aim at the control of the time available for action and it is unnecessary to introduce higher-order concepts such as the estimation of accident risk in order to explain the tactical choices of the driver. *Strategic adaptations* are changes in performance criteria that can take the form of changes in the priorities of different subtasks. In order to reduce task demands, operators can choose to concentrate on high-priority aspects of a task and relax their efforts in other sub-tasks. The results of the experiments show that drivers protect their performance in collision avoidance, whereas steering performance deteriorates in the course of prolonged driving. Strategy shifts can occur if task demands increase or if the motivation to invest effort in the task decreases.

Time pressure causes a lack of flexibility of driving behaviour. Under time pressure, drivers choose higher speeds and are reluctant to adapt their speed to changes in traffic conditions. Thus, drivers tolerate the uncertainty associated with high speeds and short headways in order to arrive at their destination in time. The results suggest that in normal circumstances, an increased accuracy of reactions compensates for the lack of adaptation of tactical choices. However, the combination of time pressure and fatigue causes an increased criticality, despite the increased accuracy of reactions. It can be concluded that the combination of time pressure and decreased motivation induces short safety margins.

The experiments described in this thesis show that drivers adapt their behaviour to changes in the traffic situation and try to protect the primary task goals. The central idea in this thesis is that traffic safety research should focus on actual driving behaviour in dynamic situations rather than on isolated driving skills. It would be useful to study individual differences in adaptation of speed and headway to changes in the traffic situation. There might be a relation between the adaptivity of driver behaviour and driving experience for example. Moreover, research that aims at the development and evaluation of traffic safety measures should take the adaptivity of driving behaviour and the effects of time pressure into account.